27

DECAY OF IONIZATION BELOW THE F-LAYER AT NIGHT

P. BANDYOPADHYAY AND S. K. CHATTERJEE

INSTITUTE OF RADIOPHYSICS AND ELECTRONICS, CALCUTTA UNIVERSITY

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ABSTRACT. Titheridge's (1959 *b*) experimental results of variation of the total amount of ionization below the night-time *F*-layer have been re-examined. It has been shown that it is not possible, on the basis of the above results, to discriminate between Titheridge's constant α-model and Mitra's (1957*a*, *b*) time dependent α-model. On other physical grounds, however, it is concluded that while Titheridge's model will possibly hold in the upper part of the region studied, Mitra's model will be valid near the bottom.

1. INTRODUCTION

Ionization in the different ionospheric layers below the *F*-region decays rapidly after sunset and as the plasma frequency f_N of the ionization goes below f_{lim}, the low-frequency limit of the ionosonde--usually 1.0 mc/s—the ionization can no longer be 'seen' in the ionogram. A residual ionization, however, then persists at these levels throughout the night. Recently, Titheridge (1959a) has developed a method of estimating the total amount of this low-lying ionization extending downwards from the bottom of the *F*-layer (where f_N equals 1.0 mc/s) upto *D*-region heights. He has studied by this method its nocturnal variation over Slough and Watheroo in different seasons and at different epochs of the sunspot cycle. The observed variation of the ionization has been interpreted by Titheridge (1959b) to mean that throughout the above height range (200-100 km. roughly) the recombination coefficient remains constant with time around an average value of 1.9×10^{-8} cm³/sec.

This conclusion of Titheridge, as applied to the lowermost levels of the above height range, is in contradiction with the recombination coefficient model as suggested by Mitra (1957a, b). In the model of Mitra the night-time recombination coefficient, α, at these heights does not remain constant but decreases with time from about 3×10^{-8} cm³/sec. at sunset to 3×10^{-9} cm³/sec. at midnight.

It is the purpose of this note to re-examine Titheridge's results on the basis of a possible time variation of the night-time recombination coefficient as in Mitra's model and assumed valid for the whole of the height range in question. It will be shown that the variation of the total amount of the low-lying ionization is insensitive to the α-model used. Consequently, it is not possible, on the basis of Titheridge's results, to discriminate between his 'constant' α-model and

Mitra's 'time dependent' α-model or to find an upper height limit to the range of validity of the latter model. On other physical grounds, however, it can be shown that while Titheridge's model will probably hold for the upper part of the height range in question, Mitra's model will be valid near the bottom.

2. INTERPRETATION OF RESULTS

For α constant in time, the nocturnal variation of the total amount of the low-lying ionization is given by

$$\frac{n(t)}{n(0)} = \frac{1}{1+\alpha N_0 t} \qquad \ldots (1)$$

where $n(t)$ is the value of the total ionization at any time t and $n(0)$ the value of the same at sunset ($t = 0$) and αN_0 is assumed constant with height.

Curves marked T_1, T_2, and T_3 in Fig. 1 show this variation for three possible values of αN_0 chosen by Titheridge, namely 0.5×10^{-3} sec.$^{-1}$, 1.0×10^{-3}sec^{-1} and 2.0×10^{-3} sec^{-1}. His conclusion about constancy of α with time from sunset to midnight is based on the fact that the different sets of his experimental points

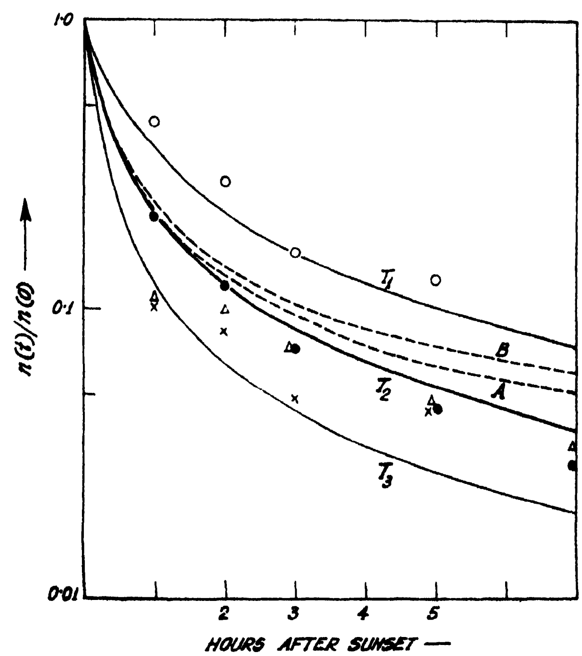

Fig. 1. Relative amount of ionization below night-time F-layer. Solid lines show the variation after Titheridge for three different values of αN_0 when α is independent of time. Broken lines show the variation for the same initial value of αN_0 as the curve marked $T2$ but with α dependent on time. Open circles, filled circles, triangles, and crosses indicate different sets of experimental values obtained by Titheridge.

(circles, triangles and crosses in Fig. 1) for these hours follow theoretical curves of the above type fairly closely.

When, however, α is time dependent, we may proceed to calculate the variation of the total amount of the low-lying ionization as follows :

We may put, following Mitra (1954)

$$\alpha = \alpha_0 e^{-pt}$$

or since p is small

$$\alpha = \alpha_0 - mt \qquad \dots \quad (2)$$

where α_0 is the value of α at sunset.
Integration of the continuity equation,

$$\frac{\partial N}{\partial t} = -\alpha N^2 \qquad \dots \quad (3)$$

with α as given by (2) yields

$$N = \frac{N_0}{1 + \left(\alpha_0 - \frac{mt}{2}\right) N_0 t} \qquad \dots \quad (4)$$

where N_0 is the value of N at sunset. The total amount of the low-lying ionization at any time t is then given by

$$n(t) = \int_0^{h_1} N dh = \int_0^{h_1} \frac{N_0 dh}{1 + \alpha_0 N_0 t - \frac{1}{2} m N_0 t^2} \qquad \dots \quad (5)$$

where, as mentioned already, h_1 is the height at which $f_N = 1.0$ mc/s.

Integration of (5) requires an advance knowledge of the sunset electron density distribution N_0. First we use a simplified model (broken line curve of Fig. 2) in which in the height range of our interest (200 km-100 km roughly) N_0 is constant. This may be taken as the idealization of an actual profile (full line) given in Fig. 2. Assuming after Titheridge that $\alpha_0 N_0$ has no height variation

$$\frac{n(t)}{n(0)} = \frac{1}{1 + \alpha_0 N_0 t - \frac{1}{2} m N_0 t^2} \qquad (6)$$

The decay of the total ionization represented by Eq. (6) is shown in Fig. 1 (curve marked A).

The value of m used is 4.9×10^{-15} cm^3/sec^2. It is taken from Mitra's (1957a) experimental model based on the critical frequency data of the night-time E-layer at Watheroo. $\alpha_0 N_0$ is chosen as 1.0×10^{-3}/sec. to correspond to one of Titheridge's curves (marked T2) in Fig. 1. Since Titheridge's average value of α_0 is 1.9×10^{-8} cm^3/sec. the above choice of $\alpha_0 N_0$ yields N_0 as 5.3×10^4/cm^3.

A comparison of the curve marked T2 with that marked A in Fig. 1 shows that for the first few hours after sunset the difference between the two modes of decay—one with 'constant α' and the other with 'time dependent α'—does not become appreciable.

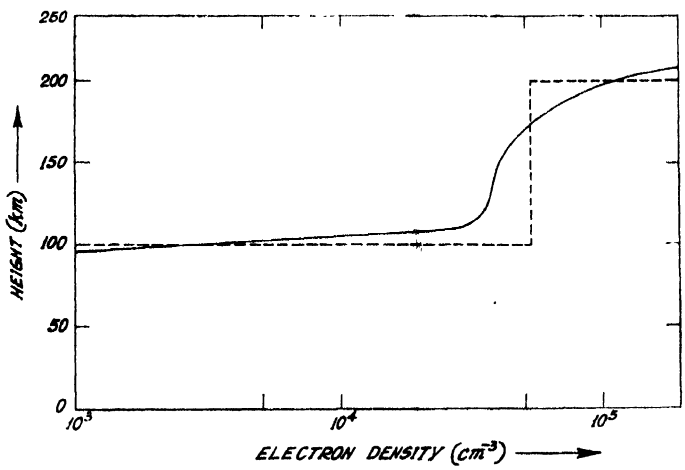

Fig. 2. Electron density distribution at sunset. Broken line curve is the idealization of an actual distribution shown by full line.

Instead of using the idealized profile of Fig. 2 we may take the actual distribution of ionization shown in the same figure. This distribution has been given by Titheridge for Watheroo at 5 minutes before sunset. Taking this to be the sunset distribution we have calculated, using Eq. (4), the ionization profiles at Watheroo for successive hours after sunset. The variation of $\frac{n(t)}{n(0)}$, as obtained by numerical integration of these profiles for heights below 200 km, is shown in Fig. 1 (curve marked B). The close agreement between this curve and those marked $T2$ and A is again noticeable.

Fig. 1 shows that the difference between the modes of decay represented by the curves marked $T2$, A and B, becomes appreciable only when observations are continued for sufficiently long hours. One may expect, therefore, that data for the later hours may be useful in distinguishing between them. At such hours, however, the situation becomes complicated by the preponderance of another factor, so far neglected, namely, the effect of vertical drift of ionization.

In the preceding calculations we have used Mitra's time-dependent α-model for the whole of the height range from the botton of the F-layer down to E-region heights. But that is just to show the insensitiveness of Titheridge's results to the recombination coefficient model chosen. On physical grounds, however, the time dependent α-model of Mitra cannot be used much beyond E-region heights. Its essential feature, namely, the time-dependence of α, is due to the slow emergence of metallic ions of the type X^+ which have a very low value of the recombination coefficient ($\sim 10^{-12}$ cm^3/sec). These ions are, most probably, meteoric in origin. Although their distribution with height is not precisely known, it is believed that their concentration will not be appreciable much above 120 or 130 km. In the absence of these ions X^+ in the higher regions, which extend up to the bottom of the F-layer, electron annihilation at night will take place, as in day-time, through dissociative recombination of the positive molecular ion O_2^+. For this case, therefore, we may use Mitra's (1959) day-time model, namely,

$$\alpha = \frac{2 \times 10^{-19} n(O_2)}{2 \times 10^{-11} n(O_2) + 1 \times 10^{-8} N}$$

where $n(O_2)$ is the concentration of neutral oxygen molecules and N is the electron density.

At first sight, it may appear that here too, α will be time-dependent because it includes electron-density N, which is variable. Actually, however, this is not so. The electron density of the low-lying ionization is always small. Hence the term involving N in the denominator of the above expression for α will remain negligible compared to the neutral particle density term upto considerable heights. Even at 200 km, near the bottom of the F-layer, and with N as 5×10^4/cm^3, a typical value, the particle density term is more than five times greater than the electron density term. Consequently, α in this region will be sensibly constant with time.

Finally, therefore, it seems probable that while the recombination coefficient has a substantial night-time variation at E-region heights up to the level where meteoric contribution to ionization has an appreciable value, in the region above and extending up to the bottom of the F-layer the coefficient is practically independent of time.

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REFERENCES

Mitra, A. P., 1954, Scientific Report No. 68, Ionosphere Research Laboratory, Pennsylvania State University.

Mitra, A. P., 1957*a*, *J. Atmosph. Terr. Phys.*, **10**, 140.

Mitra, A. P., 1957*b*, *J. Atmosph. Terr. Phys.*, **10**, 153.

Mitra, A. P., 1959, *J. Geophys. Res.*, **64**, 733.

Titheridge, J. E., 1959*a*, *J. Atmosph. Terr. Phys.*, **17**, 110.

Titheridge, J. E., 1959*b*, *J. Atmosph. Terr. Phys.*, **17**, 126.